Renewable and Sustainable Energy Reviews 16 (2012) 5485–5492

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Optimization of wind turbine micrositing: A comparative study

Samina Rajper*, Imran J. Amin

Department of Computing, SZABIST Karachi, Sindh, Pakistan

ARTICLE INFO

Article history:
Received 31 January 2012
Received in revised form
4 June 2012
Accepted 8 June 2012
Available online 1 August 2012

Keywords:
Wind Turbines Micrositing
Wind Farm Micrositing
Optimization
Genetic Algorithm
Spread Sheet
Wind Farm

ABSTRACT

The need for energy is an attention required issue for the developing countries. Developing countries are in the grip of the deficit of fossils or hydrocarbons sources of energy. Many countries are looking for the optimal solutions of energy production which are more reliable, pollution free and presume less cost. Pakistan is also in the list of those countries who want to get rid of expensive and polluted means of power production. Power production to fulfill the demand of the country is the biggest challenge for Pakistan. Therefore, many sites are under consideration for greener solutions of the problem. The proposed study is undertaken for the under consideration site, Gharo, Sindh, Pakistan. The present research is undertaken to find out the optimal solution for the wind turbine micrositings. A comparison of present study with different past studies (using different optimization techniques, i.e., genetic algorithm, Monte Carlo simulation method etc.) have been undertaken to prove the results of the present study as better results. The basic objective of the study is to find out the most optimal solution for cost per unit power; therefore, the number of wind turbines is not an issue in the undertaken study however, cost is the function of number of wind turbines and to optimize the solution, MS-Excel is used first to prove that power is a function of Wind speed. Second, genetic algorithm is also used for minimal value of fitness function.

Contents

1. Introduction

Human development depends upon the achievements of economic, social and environmental goals. But, the energy is being produced and the way it is being used is questionable to human survival [1]. It was warned by Arrhenius a century ago

* Corresponding author.
E-mail addresses: Samina.rajper@gmail.com (S. Rajper), Imran.amin@szabist.edu.pk (I.J. Amin).

1364-0321/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.rser.2012.06.014

that the emission of CO_2 from fossil fuel burning would cause the earth warming [2]. In the current scenario the fossil fuel greenhouse theory proves to be more realistic and it has been found that there is direct contact between fossil fuel burning and environmental impacts [2]. Wind technology belongs to second generation of renewables. It is very reliable technology and operating with availabilities of approximately 98%. It has a life of design of twenty or may be more than 20 years [3]. The earliest references in literature states that by 13th century most of the European countries were using wind mills [4]. In the last few decades the high demands for energy is the key issue for Pakistan and the same situation will be expected in future years. In Pakistan 45% of total commercial energy supply depends upon oil while 34% is the share of natural gas and 15% is the contribution of hydro power. On the other hand, the great rise in cost of fossil fuel and many other environmental problems have encouraged the increase in power generation from other non-conventional power generation sources [5]. Pakistan has 1046 km coastline in the south and wind speed at average rate is found 7.4 m/s or some times more than the mentioned figure. In Gharo, air corridor and the estimated wind potential is more than 50,000 MW. Other sites in Baluchistan, Punjab and northern areas are being identified also [6]. Therefore, the present research is undertaken to find out the optimal solution for the wind turbine micrositings. A comparison of present study with different past studies (using different optimization techniques, i.e., genetic algorithm, Monte Carlo simulation method etc.) have been undertaken to prove the results of the present study as better results. Two important points are considered for the present study:

- The basic objective of the study is to find out the most optimal solution for cost per unit power; therefore, the number of wind turbines is not an issue in the undertaken study.
- The hypothesis "power is the function of wind speed" is first proved using MS-Excel.

Genetic algorithm is also used for minimal value of fitness function. Finally, the results of all previous studies following the same wake model and cost function (with any techniques for optimization) are compared to the current results. Section 2 of the paper will brief some related past research works.

2. Experimental comparison with related past work

Systematic approach to wind turbine placement is an issue. The first systematic approach for wind turbine placement was introduced by Mosetti et al. [7]. In this study Jensen's analytical wake model [12] is used to model the wakes of the wind turbines. The objective function was cost per unit power to obtain the optimal results for three cases:

(a) Constant wind speed for a unidirectional scenario.
(b) Variable wind direction but the wind speed was considered as constant.
(c) Variable wind direction with variable speed.

A coarse grid with a distance of 200 m, i.e., five wind turbine rotor diameters was considered. The wind turbine with following characteristics was used:

- Hub height was 60 m (z)
- Rotor radius was 40 m (r_r)
- Thrust coefficient was 0.88 (C_T)

This study proposed a genetic algorithm to carry out the problem for the optimal placement of the wind turbines. The model that was proposed by this study defined a square grid for the placement of the wind turbines. The computational field was divided into 100 cells to place a wind turbine in the center of each cell. Jensen's wake effect model and a cost model, i.e., providing a reduction of 1/3 in the cost of each wind turbine. It must be mentioned here that all the studies to improve the results are conducted on the basis of this study [7,15].

In Grady's experiment, the same strategy was used that was already be done by Mossetti et al. [7]. Again a square grid was divided into 100 possible turbine locations and was used as the computational domain for the numerical method. The width of each cell was 5D or 200 m, in the center of which a wind turbine was to be placed. The width of 5D or 200 m was giving the domain dimensions of 50D_50D. On the basis of the dimensions of the computational domain, the maximum radius of the wake from a single turbine placed in the position x, $y=100$ m, 100 m is 189.9 m. The same wind turbine characteristics were used which are mentioned in Table 1 for the present study.

In Grady's study for case (a), the same wake model was selected and the characteristic of this wake model is that it increases in diameter as a function of downstream distance. Only one 10 column location was optimized and then the results were traced out to the whole computational domain. Grady called the Mossetti's solution as Heuristic. According to Grady et al. the difference in results in comparison of Mossetti's study may be due to the coding difference. In Mossetti's work a population of 200 individuals was allowed to be evolved over 400 generations, and also the convergence was to be determined to reach convergence. While in Grady's study, 600 individuals were distributed among 20 subpopulations and those were to evolve over 3000 generations.

Using the same wake effect model, cost model, coarse grid strategy and genetic algorithm (GA), Grady et al. [8] proposed better results than Mossetti et al. for all three cases.

In comparison of Grady et al.'s work, Marmidis et al. [9] proposed more optimal results using the same wake and cost models but they used Monte Carlo simulation method instead of using the GA. Monte Carlo method works on the basis of use of random numbers generation. Monte Carlo method deals with two types of problems, i.e., probabilistic or deterministic. For Marmidis' study, a probabilistic problem is to be dealt with as the solution were influenced directly from random numbers.

Emami et al. [10] also used the same method and proposed the results. This study proposed a modified objective function of the problem already carried out by the above-mentioned authors.

While another author Mittal [11] proposed more optimal results using GA, the same wake and cost models. However, the coarse grid was considered as $2\text{ km}\times 2.2\text{ km}$ to provide extra buffer to wind turbine micrositings. In Mittal's study a Matlab code called wind farm optimization using a genetic algorithm (WFOG) was developed to optimize the placement of wind turbines in a large wind farm. The main objective of this study was to minimize the cost per unit power.

Beyer et al. [14] provided optimal solutions for three different wind farm configurations but on the same time they used expert guess configurations. Those expert guesses were based on values for the averaged spatial density of the wind turbines, i.e., one wind turbine per three or four rotor diameter square area. The analysis was simplified by using only a single wind speed. So, it

Table 1
Wind turbine characteristics.

Hub height (z)	60 m
Rotor radius (r_r)	40 m
Coefficient thrust (C_T)	0.88

proves that researchers used expert guess also to verify their hypothesis. In the current study, the calculations are made first using spread sheet then genetic algorithm.

3. Numerical method of the present study

3.1. Wake effect model selected for the study

For the present study analytical wake model named as Jensen's wake model [12] is chosen (as per previous studies), because momentum is considered as conserved inside the wake by this model. Also for every single wake consideration, the close to field behind the wind turbine is ignored. This assumption states that the wake is turbulent. The wake expands linearly with downstream distance. Therefore, this model is suitable for the far wake region. The wake has a radius, at the turbine which is equal to the turbine radius r_r, while, r_1 is the radius of the wake in the model. r_1 is considered as radius of the wake; the relationship between r_1 and x is that downstream distance when the wake spreads downstream the radius r_1; that increases linearly proportional, x.

The wake expands linearly with downstream distance, as stated in Jensen's model as shown in Fig. 1. Bitz theory is useful in determining the wind speed after the rotor; Eq. (2) is used to determine the wind speed:

$$u = u_0\left[1 - \frac{2a}{1+\alpha(x/r_1)}\right]. \quad (2)$$

In the above equation we have: U_0 is the mean wind speed or which can be explained as the free stream wind speed, the axial induction factors is denoted by a, which can be calculated from the C_T, thrust coefficient. This can be determined from the expression:

$$C_T = 4a(1-a). \quad (3)$$

Where x is considered as the distance downstream of the turbine, while r_1 is related with r_r as represented using following equation:

$$r_1 = r_r\sqrt{\frac{1-a}{1-2a}}. \quad (4)$$

In Eq (2), α is the entertainment constant and by using the following equation; it can be obtained:

$$\alpha = \frac{0.5}{\ln(\frac{z}{z_0})}. \quad (5)$$

In the above equation, z is used to denote the hub height and roughness of the surface is denoted by z_0. The value for surface roughness varies from field to field. For plain terrains the value for z_0=0.3. Jensen's model has an extension for the cases in which the wind turbines are encountering multiple wakes from different wind turbines.

$$u_i = u_0\left[1 - \sqrt{\sum_{i=1}^{Nt}(1-\frac{u}{u_0})^2}\right]. \quad (6)$$

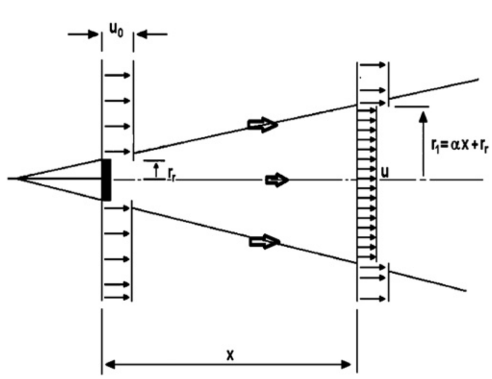

Fig. 1. Schematic of wake model [7–12].

Summing up the discussion about the Jensen's model, the cost calculation dependent on the number of turbines and for the energy production; the position of the wind turbines placement is of equal importance as the number of wind turbines.

3.2. Equation for power calculation

The power can be calculated by its availability in wind using the following equation:

$$Available\ Power = \frac{1}{2}\rho A u^3. \quad (7)$$

Assuming so as to the power production from each wind turbine contains the efficiency of wind turbine also, then we have the following equation for the energy or power generated from a wind turbine.

$$Power\_produced = \eta\frac{1}{2}\rho A u^3. \quad (8)$$

Assuming that the efficiency of wind turbine η is equal to 40% then the equation will become:

$$Power\_produced = \frac{40}{100} \times \frac{1}{2} \times 1.2 \times \pi \times (20)^2 \times u^3. \quad (9)$$

This will be derived as:

$$Power\_produced = 301 \times u^3\ \ W. \quad (10)$$

For the calculation of power into kW we have the following equation:

$$Power\_produced = 0.3u^3\ \ kW. \quad (11)$$

Power calculation equation is the function of velocity/wind speed of a turbine. Therefore, it is essential that before calculating the power of the particular wind turbine, its wind speed/velocity should be calculated using Jensen's analytical model.

3.3. Efficiency calculation

Efficiency is a term which is used for the amount of energy extracted as a part of the total energy available [10,13]. The efficiency can be applied to the wind turbines in the context of the aerodynamic efficiency of the rotor or blade, i.e., measure of the energy extracted from the wind by the blades. It has a theoretical limit of Betz limit. The efficiency can be calculated from the following equation:

$$Efficiency = \frac{\sum_{i=1}^{Nt} 0.3 \times {u_i}^3}{Nt(0.3 \times {u_0}^3)}. \quad (12)$$

Or

$$Efficiency = \frac{Power_{Total}}{Nt(0.3 \times {u_0}^3)}. \quad (13)$$

3.4. Cost model

The cost model that is used to undertake the present study is same as that was used in earlier studies [7–11]. This model facilitates a reduction of 1/3 in cost (a concession in cost) for each new wind turbine installation [7–11]. Therefore, it can be said that this cost model is a function of number of turbines

installed. From the above view the total cost can be articulated using the following equation:

$$Cost = N_t\left[\frac{2}{3}+\frac{1}{3}e^{-0.00174 N_t{}^2}\right]. \tag{14}$$

here N_t shows the number of turbines. Fig. 2 depicts that this model provides a decrease of 1/3 in cost for every additional wind turbine installation. Because Fig. 2 is highlighting the cost of 100 wind turbines but the total cost for 100 turbines is less than 100 wind turbines. This implies that the cost model is true at 1/3 reduction Fig. 3.

3.5. Wind turbine characteristics

The wind turbine selected for the current study was the same as taken by the previous studies [7–11]. The wind turbine can be characterized using Table 1.

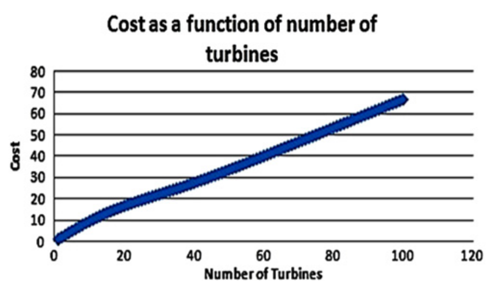

Fig. 2. Depicts cost is function of number of wind turbines.

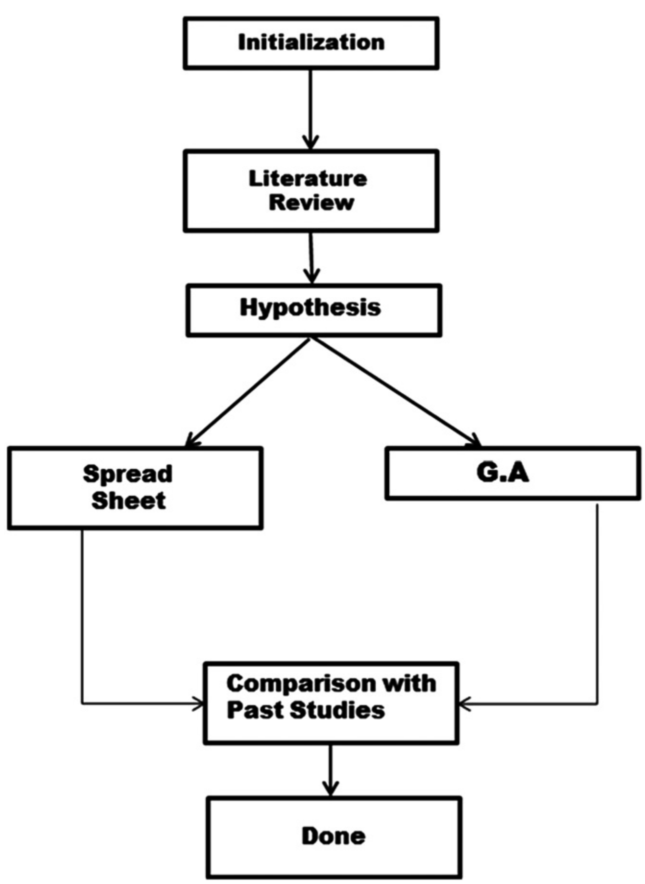

Fig. 3. The flow chart of the study.

4. Optimization process

The study for taking the results has been conducted into two phases. After literature review and study of the previous studies regarding the optimization of the wind farm placement, a hypothesis was created about the positioning of the wind turbines and wind speed that the power extraction from a wind turbine is a function of velocity of wind.

4.1. Using spread sheet

Using spread sheet, wind data has been calculated using Eq. (2), of Jensen's wake model as illustrated above. A hypothetical layout was prepared about the positioning of each wind turbine. The layout was prepared followed by the previous studies considered coarse grid for land division into cells. These cells individually will be considered for the wind turbine placement [7–11]. Optimization was done using the conventional methods, i.e., excel sheet to reach the optimal results. Comparison of results of the present study was done with the previous studies [7–11]. In the next phase, a Matlab code was prepared to be handled by genetic algorithm solver using the objective function. The objective function is total cost/total power. Comparison of results of the present study was done with the previous studies [7–11].

4.2. Calculation

For the calculation of wind speed for each wind turbine, it is believed that "power is the function of wind speed". Therefore, the wind turbines must be set or placed in such a way that maximum wind turbines must gain the direct wind speed. To implement this concept, the wind turbines are not placed in the center of the cells of the computational area but as Mittal [11] did in the conducted study that the wind turbines can be placed in anywhere in the cell of the computational area. In this study, Fig. 5 is proposed layout of the wind turbines placement, which shows that first 10 wind turbines of first row and 9 wind turbines in second row of placed wind turbines are directly facing the maximum wind speed without any reduction. However, the calculation of wind speed is done using Eq. (2). The values for different variables are as under:

$X=$ 200 m
$Z=$ 60 m
$z_{0=}$ 0.3
$r_r=$ 40 m
$C_T=$ 0.88
$u_0=$ 12 m/s
$a=$ 0.326795
$\alpha=$ 0.09437

Here Eq. (2) is used to solve case (a).

When the mean wind speed is acquired on each of the wind turbine then using Eq. (11) power is calculated for each wind turbine. Finally, to achieve the objective of the study, total cost/total power gained from the specific number of wind turbines, e.g., from Table 3.

Power gained from wind turbine 1 is 518.4, i.e., power is calculated using Eq. (11).

Cost of wind turbine 1 is calculated using Eq. (14) and the cost per unit power if only one wind turbine is installed is acquired using the following Eq.

$$\frac{Total\ Cost}{Total\ Power} \tag{15}$$

Here from Table 1, the power gained from wind turbine 1 is 518.4 and its cost is 0.999420504, which is calculated using Eq. (14). Finally, Eq. (15) is used to calculate the cost per unit power.

The efficiency of the wind farm is calculated using Eq. (13), i.e., For example;

As the proposed solution of the current study the efficiency of the wind farm is 97.05619%, which can be calculated from the values as follows. The total power calculated from 54 wind turbines is 27,169.52 kW. So if we put the values into Eq. (13) mentioned above, it will be:

$$Efficiency = \frac{Power_{Total}}{N_t(0.3 \times u_0{}^3)}$$

$27\,169.52/(54 \times 518.4) \times 100 = 97\%.$

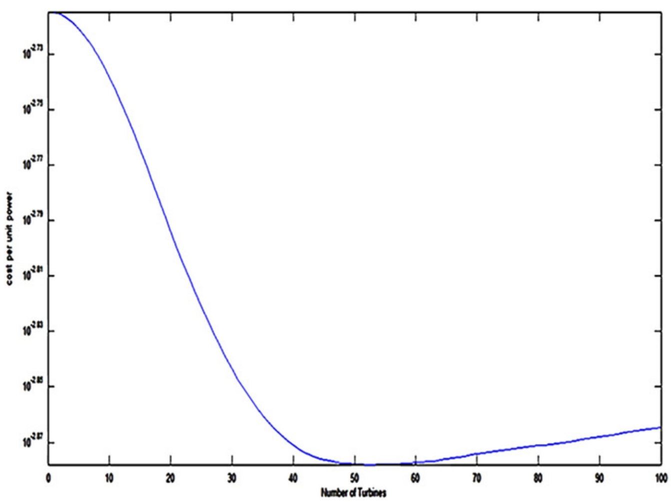

Fig. 4. The acquired curve for objective cost/unit power after using the wake model.

Table 2
Depicts the results of the present study.

Proposed number of turbines	54
Optimal objective function value	1.3292×10^{-3}
Power production	27,169.52 kW
Efficiency	97.05619%

4.3. Genetic algorithm initialization

While using the genetic algorithm, a fitness function or objective function is to be coded to be run in GA. The objective function file is used to describe the problem to the GA solver. The GA objective file is coded actually to code Eq. (2) to solve case (a). The GA solver has the following options to be initialized. If the options are not customized by the used, the GA automatically initializes these values.

a. **Number of variables:** The number of variables in this study is the number of wind turbines required for the wind farm layout, i.e., at least 100.
b. **Population size:** Population size refers to the total number of solutions in one solution set. If it is to be a vector of length greater than 1, the algorithm creates multiple subpopulations. Each entry of the vector specifies the size of a subpopulation.
c. **Generations:** Generations are referred as the number of iterations will be used by the GA solver.
d. **Selection:** For selection option "Stochastic uniform" was selected.
e. **Reproduction:** In reproduction option the Elite count is set as 2, means 2 members of individuals are guaranteed to survive to the next generation.
f. **Cross over fraction:** It refers to the fraction of the next generation that crossover produces. Here, 0.8 was set.

When all the values are set be initialized, estimated power and cost using the Matlab code is calculated and objective function for each value "GA" solution (cost/unit power) is acquired. The optimization method here is ranked based, i.e., a solution with lower fitness function is better than the higher value of objective function. For example, a solution whose objective value is 0.05 is considered better than a solution with 0.06 objective values. Therefore, using ranking the solution with lower values will be placed before the higher value solutions.

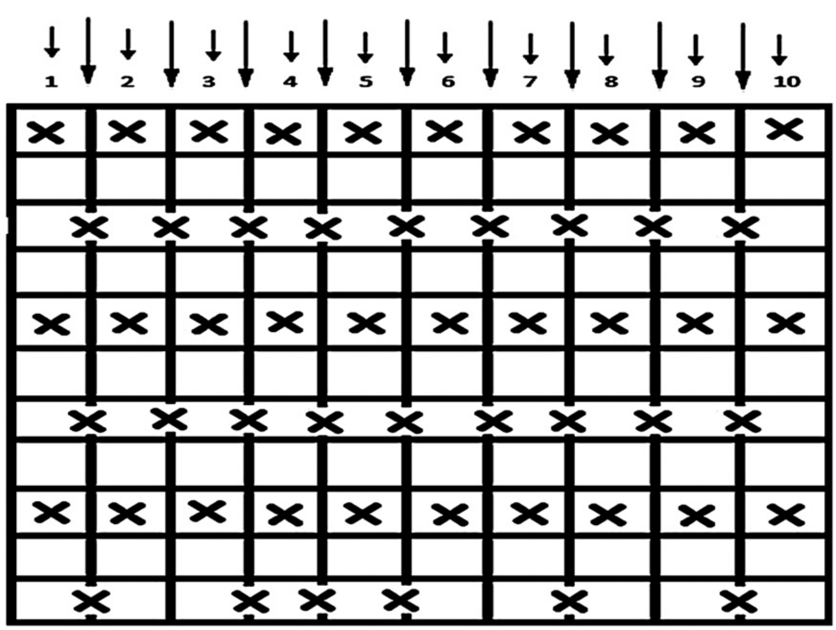

Fig. 5. Optimal layout for wind farm, showing 54 wind turbines total.

Table 3
Depicts the results for cost per unit power.

Number of turbines	Power production (kW)	Cost per unit power
1	518.4	0.0019279
2	1,036.8	0.0019246
3	1,555.2	0.0019190
4	2,073.6	0.0019114
5	2,592	0.0019016
6	3,110.4	0.0018900
7	3,628.8	0.0018765
8	4,147.2	0.0018613
9	4,665.6	0.0018445
10	5,184	0.0018263
11	5,702.4	0.0018069
12	6,220.8	0.0017865
13	6,739.2	0.0017652
14	7,257.6	0.0017432
15	7,776	0.0017207
16	8,294.4	0.0016979
17	8,812.8	0.0016749
18	9,331.2	0.0016519
19	9,849.6	0.0016291
20	10,351.68	0.0016091
21	10,853.76	0.0015893
22	11,355.84	0.0015697
23	11,857.92	0.0015506
24	12,360	0.0015321
25	12,862.08	0.0015142
26	13,364.16	0.0014970
27	13,866.24	0.0014807
28	14,368.32	0.0014652
29	14,870.41	0.0014506
30	15,372.49	0.0014369
31	15,874.57	0.0014241
32	16,376.65	0.0014123
33	16,878.73	0.0014014
34	17,380.81	0.0013914
35	17,882.89	0.0013822
36	18,384.97	0.0013739
37	18,887.05	0.0013663
38	19,389.13	0.0013595
39	19,875.4	0.0013545
40	20,361.68	0.0013501
41	20,847.95	0.0013463
42	21,334.23	0.0013429
43	21,820.5	0.0013401
44	22,306.78	0.0013376
45	22,793.05	0.0013356
46	23,279.33	0.0013339
47	23,765.6	0.0013325
48	24,251.87	0.0013315
49	24,738.15	0.0013306
50	25,224.42	0.0013300
51	25,710.7	0.0013296
52	26,196.97	0.0013293
53	26,683.25	0.0013292
54	27,169.52	0.0013292
55	27,655.8	0.0013293
56	28,142.07	0.0013294
57	28,628.34	0.0013297
58	29,099.31	0.0013307
59	29,570.28	0.0013317
60	30,041.24	0.0013328
61	30,512.21	0.0013338
62	30,983.17	0.0013349
63	31,454.14	0.0013359
64	31,925.11	0.0013370
65	32,396.07	0.0013380
66	32,867.04	0.0013391
67	33,338	0.0013401
68	33,808.97	0.0013411
69	34,279.94	0.0013421
70	34,750.9	0.0013430
71	35,221.87	0.0013440
72	35,692.83	0.0013449
73	36,163.8	0.0013458
74	36,634.76	0.0013467
75	37,105.73	0.0013475
76	37,576.7	0.0013484
77	38,032.84	0.0013497
78	38,488.98	0.0013511
79	38,945.12	0.0013523
80	39,401.26	0.0013536
81	39,857.4	0.0013548
82	40,313.54	0.0013560
83	40,769.68	0.0013572
84	41,225.82	0.0013584
85	41,681.96	0.0013595
86	42,138.1	0.0013606
87	42,594.24	0.0013617
88	43,050.38	0.0013627
89	43,506.51	0.0013638
90	43,962.65	0.0013648
91	44,418.79	0.0013658
92	44,874.93	0.0013668
93	45,331.07	0.0013677
94	45,787.21	0.0013687
95	46,243.35	0.0013696
96	46,685.14	0.0013709
97	47,126.92	0.0013722
98	47,568.7	0.0013735
99	48,010.48	0.0013747
100	48,452.26	0.0013759

Table 4
Mossetti vs. present study at the results of 26 turbines.

	Mossetti et al.	**Present study**
Number of turbines	26	26
Power production	12352	13364.16
Objective function (using excel sheet)	0.0016197 (used GA only)	0.0014970
Objective function (using GA)	0.0016197	0.001423
Efficiency	91.645%	99.15245%

Table 5
The table dhows the results of Grady et al. vs. present study.

	Grady et al.	Present study
Number of turbines	30	30
Power production	14,310	15,372.49
Objective function (using spread sheet)	0.0015436(used GA only)	0.0014369
Objective function (using GA)	0.0015436	0.001423
Efficiency	92.015%	98.84572%

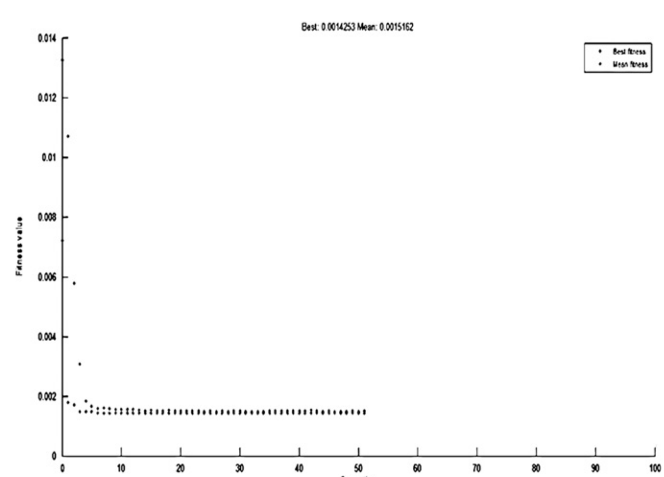

Fig.6. Depicts the fitness function value using GA.

5. Results and discussion

In this section, the results acquired using the Jensen's model will be discussed and later the results will be compared to the results of previous studies [7–11]. All calculations of velocity and alternate changes in wind speed on a wind turbine are calculated using excel sheet. In the current study, first case is solved with two techniques and compared the results with previous studies.

CASE: Uniform wind speed and uni-directional wind.

- Wind Speed was initially considered as 12 m/s as in earlier studies [7–11].
- Wind direction is considered as from left to right as per earlier studies [7–11].

Table 6
The table shows the results of Marmidis vs. the present study (at 32 wind turbines).

	Marmidis	Present study
Number of turbines	32	32
Power production	16,395	16,376.65
Objective function	0.0014107	0.0014123
Objective function (using GA)	0.0014107	0.001423
Efficiency	Not reported	98.72111

Table 7
The table shows the results of Mittal vs. the present study (at 44 wind turbines).

	Mittal	Present study
Number of turbines	44	44
Power production	21,936	22,306.78
Objective function (using excel sheet)	0.0013602 (used GA only)	0.0013376
Objective function (using GA)	0.0013602	0.001423
Efficiency	96.1%	97.79%

- All previous studies except Mittal used 2 km long and 2 km wide area. The previous studies [7–11] used 100 possible locations for the placement of wind turbines. But Mittal used 2 km wide and 2.2 km long area for the optimal layout of the wind farm. According to Mittal's study, if the wind turbines are set closed the more velocity deficit can be resulted. In other words, this leads the lower power production from the wind turbines. Hence, close combination of wind turbine placement will increase the cost per unit power. For the present study a wind farm is considered, its length is 2.2 km and width is 2 km. Keeping the facts in view, the optimization is done using the excel sheet based on Jensen's analytical wake model.

5.1. Results using the spread sheet

First the optimal results are obtained following the wake model [12] using excel sheet. The foundation (Hypothesis) of the study is stated in the previous section.

The graph in Fig. 4 depicts the clear picture of above statement that minimum cost can be achieved if the favorable power production is acquired from a particular number of wind turbines. The graph depicts that the objective function provides the reduction in cost in the manner that as the number of wind turbines increases, there is a reduction in the average cost of one wind turbine. Hence, the cost is starting to decrease.

The graph in Fig.4 depicts that cost is continuously reducing, i.e., applying the objective function cost over total power and when the number of turbines reach to 50, it is going to be optimized and from the 53 number of wind turbine and 54 the data for cost/unit power is found as 0.0013292 or 1.3292×10^{-3} which shows the most optimal figure in Table 2 showing the total calculation for acquiring the most optimal cost/unit power. It is crystal clear from Fig. 5 and from Table 3 that when the 55th wind turbine is added, the cost per unit power immediately increases and it reaches to the amount 0.0013293 or 1.3293×10^{-3} that is more than the previous amount. Hence, the most optimized cost/unit power is considered when the cost/ unit power of 53rd and 54th wind turbines is acquired as 0.0013292 or 1.3292×10^{-3}.

It should be considered here that when the number of wind turbines go beyond the 54, the cost/unit power goes towards the

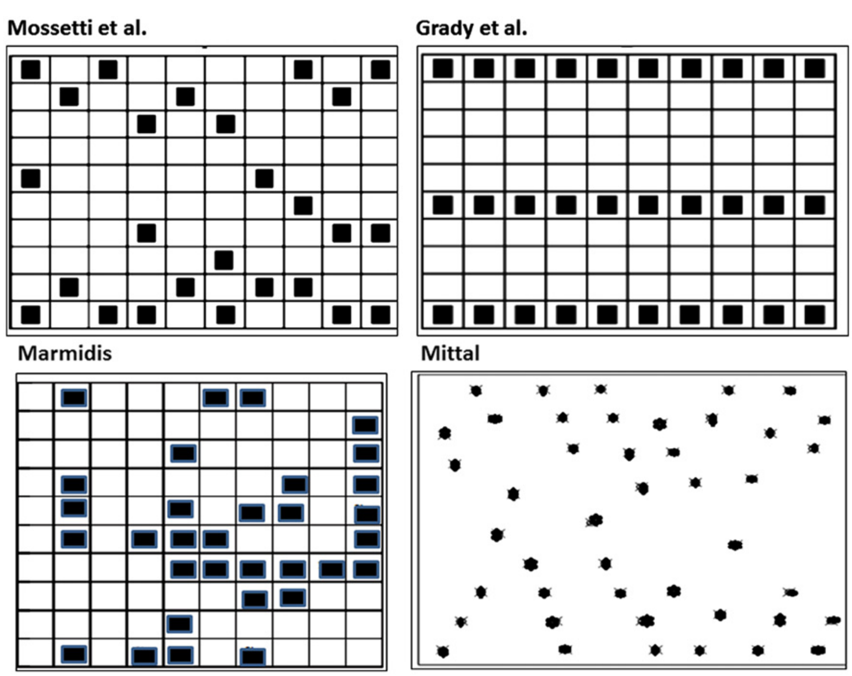

Fig. 7. The figure shows the finally proposed as optimal layout of the wind farm by previous studies.

continuous increase because it is known that as more and more wind turbines are installed in a wind farm, there will be an increase in the wake losses, at the same time this addition can lead to an uneconomical solution of the problem. Therefore, for the present study only cost/unit power was the focus and achieved 100%. The optimal layout of these 54 wind turbines are shown in Fig. 5.

However, the layout of 53 winds turbines cannot be considered as the most optimal solution because it is questionable if both configurations of 53 and 54 wind turbines depicts the same cost/ unit power, i.e., 0.0013292 or 1.3292×10^{-3}, but the total power production from the 53 wind turbines is 26,683.25 kW which is less than the power production of 54 wind turbines which is 27,169.52 kW power. As stated earlier the objective of undertaking this study is to acquire the most optimal solution for the minimal cost per unit power. Therefore, the more power at the same cost is considered more optimal than the less power production at the same cost. Therefore the final configuration of wind turbines which are 54 in number can produce 27,169.52 kW power and 97.05619% is obtained as the acquired wind farm efficiency.

The results of the present study are depicted in Tables 4 and 5.

5.2. Results from genetic algorithm solver

On the other hand a Matlab function is used as fitness function to minimize the objective function cost per unit power is used. The objective function file is used to describe the problem to the GA solver. Same concept is coded using Matlab and using fitness function the cost/power function is optimized. The final value for fitness function acquired as 0.001423 or 1.423×10^{-3} after running GA for many times. The 100 number of variables are used for optimization. Using 100 generations the GA gave the mentioned result Fig. 6.

6. Comparison of present study with the previous studies

The present study is undertaken in the context of the previous studies, i.e., Mossetti et al., Grady et al., Marmidis and Mittal. The results of the present study are compared at each stage to the other studies as all other studies have depicted different results for number of turbines, power production, cost and efficiency of the wind farm. It is considered for the comparison of different studies with the present study that all the studied worked to solve the problem of optimization of wind turbines micrositing and the objective function is same cost/ power; also the same Jensen's wake model, equation for power extraction, equation for efficiency and same cost function is followed Tables 6 and 7.

The results of the Marmidis are different from the present study and do not match. Because the optimization by the Marmidis was done using a program code; developed in Matlab, and the Monte Carlo simulation method was used for optimization Fig. 7.

7. Conclusion

The Present study is under taken to solve the case of constant wind speed for uni-direction wind speed. The characteristics of the terrain were considered for the available land at Gharo, Thatta, Sindh. The terrain is a plain terrain. The results of the objective function using excel sheet and genetic algorithm solver are depicted above. The conducted study proposed a final optimal layout for the said terrain with 54 turbines. The overall efficiency of the proposed configuration is calculated as 97.05619% with a maximum power production as 27,169.52 kW and the minimum value for the cost per unit power is calculated as $1.3292 \times 10^{-3.}$

Hence, the study successfully, reached the optimal solution for the minimum cost per unit power function, at the maximum power production with an improved efficiency value of Wind farm and also the optimal layout for the configuration of the wind turbines micrositing is proposed. The placement is proposed with utilizing the maximum land of the available terrain keeping in view the fact; "Power is the function of wind speed".

References

[1] World Energy Assessment, Energy and the challenge of sustainability. United Nations Development Program 2000.
[2] Hoffert MI, Caldeira K, Benford G, Criswell DR, Green C, Herzog H, et al. Advanced technology paths to global climate stability: energy for a greenhouse planet. Science 2002;298(1).
[3] International Energy Agency, Renewables in global energy supply. An International Energy Agency Fact Sheet, 2007.
[4] SM Nasir, Estimation of wind energy potentials in Pakistan. PhD thesis. Quetta: University of Balochistan; 1993.
[5] Chaudhry Q. An investigation of wind power potential at GHARO-SINDH. Pakistan Journal of Meteorology 2009;6(11).
[6] Saifullah , Joint Secretary (Power) Ministry of Water and Power Government of Pakistan, Opportunities & challenges to scaling up Wind power in Pakistan. In: A presentation in quantum leap in wind power in Asia—Structured consultation; 2010.
[7] Mosetti G, Poloni C, Diviacco B. Optimization of wind turbine positioning in large wind farms by means of a genetic algorithm. Journal of Wind Engineering and Industrial Aerodynamics 1994;51:105–16.
[8] Grady SA, Hussaini MY, Abdullah MM. Placement of wind turbines using genetic algorithms. Renewable Energy 2005;30:259–70.
[9] Marmidis G, Lazarou S, Pyrgioti E. Optimal placement of wind turbines in a wind park using Monte Carlo simulation. Renewable Energy 2008;33: 1455–60.
[10] Emami A, Noghreh P. New approach on optimization in placement of wind turbines within wind farm by genetic algorithms. Renewable Energy 2010;35:1559–64.
[11] Mittal A, Optimization of the layout of large wind farms using genetic algorithm. MS thesis, Department of Mechanical and Aerospace Engineering Case Western Reserve University; 2010.
[12] Jensen NO. A note on wind generator interaction. Roskilde, Denmark: Riso National Laboratory; 1983.
[13] Chunqiu W, Jun W, Geng Y, Xiaolanand L, Xing Z, Optimal micro-siting of wind turbines by genetic algorithms based on improved wind and turbine models. In: Joint 48th IEEE conference on decision and control and 28th Chinese control conference, Shanghai, PR China; 2009.
[14] Beyer HG, Ruger T, Schafer G, Waldl HP, Optimization of wind farm configurations with variable number of turbines. In: Proceedings of the European Union wind energy conference (EUWEC), Sweden, pp. 1069–1073; 1996.
[15] Salcedo-Sanz S, Saavedra-Moreno B, Paniagua-Tineo A, Prieto L, Portilla-Figueras A. A review of recent evolutionary computation-based techniques in wind turbines layout optimization problems. Central European Journal of Computer Science 2011;1:101–7, http://dx.doi.org/10.2478/s13537-011-0004-2 issue , pp 101–107.